Definition of Sediment Toxicity Zones around Oil Development Sites: Dose Response Relationships for the Monitoring Surrogates Microtox® and Amphipods, Exposed to Hibernia Source Cuttings Containing a Synthetic Base Oil

J. Payne, C. Andrews, S. Whiteway and K. Lee

August 2001

Science, Oceans and Environment Branch
Department of Fisheries and Oceans
P. O. Box 5667
St. John's, NF AIC 5X1

Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 2577

Fisheries and Oceans Pêches et Océans

Canada

101-07068/

Definition of Sediment Toxicity Zones around Oil Development Sites: Dose Response Relationships for the Monitoring Surrogates Microtox® and Amphipods, Exposed to Hibernia Source Cuttings Containing a Synthetic Base Oil

J. Payne, C. Andrews, S. Whiteway and K. Lee

August 2001

Science, Oceans and Environment Branch
Department of Fisheries and Oceans
P. O. Box 5667
St. John's, NF AIC 5X1

Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 2577

Canadian Manuscript Report of
Fisheries and Aquatic Sciences No. 2577

August 2001

Definition of Sediment Toxicity Zones around Oil Development Sites: Dose Response Relationships for the Monitoring Surrogates Microtox® and Amphipods, Exposed to Hibernia Source Cuttings Containing a Synthetic Base Oil

by

J. Payne[1], C. Andrews[1], S. Whiteway[2] and K. Lee[3]

[1]Science, Oceans and Environment Branch
Department of Fisheries and Oceans
P.O. Box 5667
St. John's NF A1C 5X1

[2]Jacques Whitford Environment Limited
607 Torbay Road
St. John's NF A1A 4Y6

[3]Maurice Lamontage Institute
Department of Fisheries and Oceans
P.O. Box 1000
Mont-Joli Quebec G5H 3Z4

©Minister of Public Works and Government Services 2001
Cat. No. 97-4/2577E ISSN 0706-6473

Correct citation for this publication:

Payne, J., C. Andrews, S. Whiteway, and K. Lee. 2001. Definition of sediment toxicity zones around oil development sites: dose response relationships for the monitoring surrogates Microtox® and amphipods, exposed to Hibernia source cuttings containing a synthetic base oil. Can. Manuscr. Rep. Fish. Aquat. Sci. No. 2577: vi + 10 p.

CONTENTS

Abstract v

Introduction 1
1. Sediment Preparation 3
2. Alkane Analysis 3
3. Microtox® 4
4. Amphipod Survival 4
5. Fuel Range (C11-C20) and Lube Range (C21-C32) Hydrocarbons for Hibernia Environmental Effects Monitoring Sediment Stations for 1999 5
6. Extrapolations of Size of Toxic Zones 7

Conclusions 8

Acknowledgements 8

References 9

ABSTRACT

Payne, J., C. Andrews, S. Whiteway, and K. Lee. 2001. Definition of sediment toxicity zones around oil development sites: dose response relationships for the monitoring surrogates Microtox® and amphipods, exposed to Hibernia source cuttings containing a synthetic base oil. Can. Manuscr. Rep. Fish. Aquat. Sci. No. 2577: vi + 10 p.

Microtox® and amphipod bioassays are commonly employed as monitoring surrogates for sediment toxicity including around oil development sites. Dose-response relationships have been developed for these surrogates in studies with authentic Hibernia source cuttings containing an aliphatic hydrocarbon based drilling fluid. The cuttings demonstrated a similar and very low acute toxicity potential in both the Microtox® and amphipod bioassays. Distinct toxicity was demonstrated with sediments containing approximately 6000 mg/kg of diesel range hydrocarbons. Diesel range hydrocarbons are also being measured in sediments in monitoring programs in the offshore. This permitted extrapolations to be carried out on the potential size of toxic zones for the monitoring surrogates stemming from disposal of drill cuttings enriched in the drilling fluid in question. The first extrapolation was carried out on the basis of constant hydrocarbon input over time in relation to reference concentrations found at various distances from the rig site after 2 years of development. The other extrapolation was carried out assuming 36% of the wells have already been drilled. Both extrapolations indicated little or no risk for toxicity to sediment monitoring surrogates even as close as 1000 m or less from the rig site over the life of the project. Risks could also be further reduced at development sites with greater contaminant dispersion potential.

RÉSUMÉ

Payne, J., C. Andrews, S. Whiteway, and K. Lee. 2001. Definition of sediment toxicity zones around oil development sites: dose response relationships for the monitoring surrogates Microtox® and amphipods, exposed to Hibernia source cuttings containing a synthetic base oil. Can. Manuscr. Rep. Fish. Aquat. Sci. No. 2577: vi + 10 p.

Les tests microtox et amphipodes sont communément utilisés pour déterminer la toxicité des sédiments autour des plate-formes pétrolières. Les relations doses/réponses ont été étudiées en utilisant des déblais de forage de la plate-forme Hibernia contenant un liquide de forage riche en hydrocarbures aliphatiques. Les résultats des tests microtox et amphipodes ont montré une faible toxicité aigûe des déblais de forage. Une importante toxicité a été démontrée lors de l'utilisation de sédiments contenant 6000mg/kg de diesel. Les hydrocarbures associés au diesel ont été mesurés dans les sédiments autour de la plate-forme offshore. Ceci a permis des extrapolations sur la taille potentielle des zones toxiques en utilisant les résultats des tests microtox et amphipodes. La première extrapolation a été conduite en considérant l'apport d'hydrocarbures constant et ce en se basant sur les concentrations mesurées à des distances différentes de la plate-forme après deux ans d'exploitation. La seconde extrapolation a été réalisée en considérant que 36% des forages avaient déjà été réalisés. Les deux extrapolations ont indiqué peu ou pas de toxicité en utilisant les deux tests pré-cités et ce même à moins de 1000m de la plate-forme. Les risques pourraient être d'avantage réduits aux lieux d'exploitation avec une plus grande dispersion des contaminants.

INTRODUCTION

Oil or synthetic based drilling fluids offer a technical advantage over water based muds in that use of such formulations reduces or eliminates borehole problems and attendant risks, particularly where hole stability is a concern. The acute toxicity data available for both synthetic and water base fluids indicate that discharges from platforms into well mixed waters should result in little or no chemically mediated acute effect (Neff 1987; GESAMP 1993; Payne *et al.* 1995).

Concerns about the environmental effects of drilling waste discharges have been discussed by Ray (1989). From a regulatory perspective under the habitat provisions of the Fisheries Act, one of the key questions regarding offshore oil development on the east coast of Canada, is to define the extent of impacts on fish habitat. Field studies in the North Sea and Gulf of Mexico indicate that effects on benthic communities in situ should be more or less localized around rig sites, with oil based cuttings (diesel or similar) probably being responsible for most of the effects. A study of 40 development and 300 single well sites in the North Sea where oil-based drilling muds were used to varying degrees, indicated major effects to be mostly confined to within 250-500 m of rig sites with subtle effects sometimes occurring out to 2000 m (GESAMP 1993). Subtle effects have also been reported at a distance of 4000-5000 m from a few development sites in the North Sea (Olsgard and Gray 1995). In contrast to oil-based cuttings, more recent studies at sites where synthetic drilling muds were used indicate that effects are rarely seen outside 250-500 m (Frode Consulting 1999). Such limited zones of impact on sediment communities in the 1000 m range or greater would not be expected to translate into a significant loss or gain of fish productivity through change in prey availability. Actually with respect to bivalve productivity, water based muds may present a greater potential than synthetic muds for impacting fish resources such as scallops, through interference with feeding mechanisms (Cranford *et al.* 2001).

A synthetic based drilling fluid (IA-35) is presently being used in the Newfoundland offshore. Toxicity studies carried out on scallops as well as selected studies with plankton and fish larvae, indicate a very low potential for acute toxicity (Cranford *et al.* 2000; Armsworthy *et al.* 2000; Payne *et al.* 2001). This is supported by acute toxicity information provided by industry (not reviewed here) as well as more fundamental investigations in biochemical toxicology (Wang *et al.* 2000). Also with respect to chronic effects which are much more difficult to assess, monitoring programs being carried out around rig sites for early signs of stress in fish will be valuable for addressing concerns about the scope and magnitude of any effects on fish populations from the potential cumulative effects of synthetic and/or water based muds and production waters.

This study addresses the acute toxicity potential of muds enriched in the synthetic fluid presently being used in the offshore, for the surrogate species employed in sediment monitoring programs. Authentic drill cuttings were

obtained from Hibernia and dose-response relationships were developed for the Microtox® and amphipod bioassays. The same method of chemical analysis for hydrocarbons in sediments was used as in the Hibernia monitoring program. Given the concentrations of hydrocarbons presently found around the Hibernia rig, this permitted extrapolations to be carried out with respect to the size of impact zones for the surrogate monitoring species over the life of the project.

1. SEDIMENT PREPARATION

Drill mud cuttings from the borehole were obtained from Mr. David Taylor, Hibernia Management and Development Company and were stored in a 20L bucket at 4°C until used. The Ocean Science Centre collected sand from the beach at Lower Pond, Witless Bay, NF. Concentrations of drill mud cuttings were prepared by mixing 0, 36, 110, 330, 1000 and 4000 ml of drill mud cuttings per 54 liters of dry sand. Homogeneous mixtures were ensured by gradual addition and thorough mixing of small quantities of sand into the drill cuttings. Each concentration (referred to as E-0, E-36, E-110, E-330, E-1000 and E-4000) was transferred to six 200L tanks supplied with aerated seawater in a flow through system at the Ocean Science Centre's aquarium, Logy Bay, NF. Each tank was held under ambient conditions from March 5, 1999 to June 17-29, 1999. At the end of the exposure study, five 125 ml jars of sediment were taken from each tank and placed at –30°C until used. Sediment from three of the five 125 ml jars were pooled and stirred 20 times with a solvent cleaned spatula. A sub-sample (450-650 g) was removed for alkane analysis and shipped on ice to AXYS Analytical Services Limited, Sidney, BC. A second sub-sample (100 g) was taken from each pool for the Microtox® Large Sample Procedure (LSP) and shipped on ice to Department of Fisheries and Oceans, Bedford Institute of Oceanography, Dartmouth, NS. All samples were kept frozen until analysis. A 1 L sediment sample was also taken from each tank at the end of the exposure study and transported immediately to Jacques Whitford Environment Limited, St. John's, NF, for use in the amphipod survival bioassay.

2. ALKANE ANALYSIS

Analysis of diesel range alkanes (C10-C19) was carried out by Norwest Labs, Surrey, BC (subcontracted by AXYS Analytical Services Limited). Sediment samples (10 g) were extracted then analyzed by gas chromatography–mass spectrometry. A procedural blank, duplicate (E-330), spiked matrix and surrogate standards were run along with the samples to ensure quality assurance and quality control. The detection limit for the diesel range alkanes (C10-C19) and the lube range alkanes (C19-C32) was 1mg/kg. Results are recorded in Table 1.

Table 1: Concentration of Diesel Range Alkanes (C10 to C19) in Hibernia Drilling Mud Sediment Samples.

Sample Descriptor	Diesel Range Alkanes >C10-C19 (mg/kg)	Lube Range Alkanes >C19-C32 (mg/kg)
E-0	<1	<1
E-36	62	1
E-110	230	6
E-330	530	16
E-330	560	20
E-1000	1900	50
E-4000	6300	210

3. MICROTOX®

Microtox® Large Sample Procedure (Microbics 1992, Azur 1999) is based on suppression of the bioluminescence evolved by the marine bacterium *Vibrio fischeri* on exposure to toxicants. Sediment sample, 7.00 ± 0.004 g-wet-weight in 35.0 mL of Solid Phase Test Diluent, was used to prepare a test concentration gradient up to 197000 mg-wet-weight/L. Two aliquots of the LSP primary dilution were tested simultaneously. Toxicity was expressed as the EC_{50} value, the effective concentration that induces 50% reduction of bioluminescence relative to test controls. The E-4000 descriptor which corresponds to an alkane concentration of 6300 mg/kg (Table 1), was the only sample that showed distinct toxicity. EC50 values (>1000) are within the limits accepted by Environment Canada for the disposal of dredged sediment material (Tay *et al.* 1997).

Table 2. Results of Microtox® Large Sample Procedure for Drilling Mud Samples. The '>' indicates that the EC_{50} was greater than the highest test concentration, i.e., no detectable toxicity.

Sample Descriptor	EC_{50} (dry mg/L)
E-0	>173000
E-0	>173000
E-36	>171000
E-36	>171000
E-110	>170000
E-110	>170000
E-330	>171000
E-330	>171000
E-1000	169000
E-1000	169000
E-4000	90200
E-4000	81300

4. AMPHIPOD SURVIVAL

Test conditions for the 10-day marine amphipod bioassay was followed according to the Biological Test Method: Reference Method for Determining Acute Lethality of Sediment to Marine or Estuarine Amphipods (Report EPS 1/RM/35 December 1998). All test param were maintained within the recommended level outlined in the protocol.

Amphipod, *Rhepoxynius abronius*, was obtained from Environmental Resolution Services – Whitby Island, Seattle Oregon, US. The bioassay was set-up using 175ml of sediment under static test conditions, in a temperature controlled water bath (15°C) aerated with 2-3 bubbles/s (90–100% saturation) for 10 days. Five trials were conducted for each concentration using 20 amphipods per trial. The endpoints were recorded as mean survival (Table 3). As for Microtox®, the E-4000 exposure which corresponds to an alkane concentration of 6300 mg/kg (Table 1) was the only one that displayed distinct toxicity in relation to guidelines used by Environment Canada for ocean disposal, which is a decrease in amphipod survival of 20% or more (Porebski *et al.* 1998).

Table 3: Amphipod Survival Bioassay with Hibernia Drilling Mud Sediment.

	Trials					
Sample Descriptor	**1**	**2**	**3**	**4**	**5**	**Mean Survival (%)**
Reference Sediment	20 alive 0 dead	20 alive 0 dead	20 alive 0 dead	20 alive 0 dead	20 alive 0 dead	100
E-0	20 alive 0 dead	19 alive 1 dead	20 alive 0 dead	20 alive 0 dead	20 alive 0 dead	99
E-36	19 alive 1 dead	19 alive 1 dead	20 alive 0 dead	19 alive 1 dead	18 alive 2 dead	95
E-110	19 alive 1 dead	19 alive 1 dead	20 alive 0 dead	20 alive 0 dead	19 alive 1 dead	97
E-330	19 alive 1 dead	16 alive 4 dead	18 alive 2 dead	18 alive 2 dead	17 alive 3 dead	88
E-1000	19 alive 1 dead	18 alive 2 dead	18 alive 2 dead	17 alive 3 dead	18 alive 2 dead	90
E-4000	12 alive 8 dead	11 alive 9 dead	9 alive 11 dead	11 alive 9 dead	10 alive 10 dead	53

5. FUEL RANGE (C11-C20) AND LUBE RANGE (C21-C32) HYDROCARBONS FOR HIBERNIA ENVIRONMENTAL EFFECTS MONITORING SEDIMENT STATIONS FOR 1999 (Taken from JWEL Project No. 1355-1599. Hibernia Production Phase Environmental Effects Monitoring Program – Year Two of Production. May 2000).

Sediment samples were collected at 58 predetermined sites along a sampling grid that extends out to 8000m from Hibernia's gravity based structure (GBS) along 4 radii (N, E, S, W) and out to 4000m for 4 more radii (NE, SE, SW, NW). Also, there are two reference stations 16000m from the GBS on the N and W radii. Radials extending north, northeast, east, southeast, south, southwest, west and northwest are labeled 1 to 8, respectively. Sediment samples were taken in triplicate within a 25m radius of each defined site using a $0.25m^2$ stainless steel Pouliot Box Corer. All surfaces were free from oil and grease during sampling. Sediment samples were extracted and analyzed for fuel (C11–C20) and lubricating oil (C20-C32) range hydrocarbons using SOP# 9010, Extractable Petroleum Hydrocarbons in Soil/Sediment. The limit of quantitation for each is 0.25 mg/kg. QA/QC protocol was met by preparing procedural blanks, percent recoveries and replicate sample analysis.

Levels are taken from Figure 4.2 and 4.3 of JWEL Project No. 1355-1599. Hibernia Production Phase Environmental Effects Monitoring program – Year two of Production, May 2000, and are recorded in Table 4 and 5.

Table 4: Fuel Range (C11-C20) Hydrocarbons for Hibernia EEM Sediment Stations for 1999. Values are in mg/kg.

Distance from Rig (m)	Radial							
	1	2	3	4	5	6	7	8
250		184.7		145.3		60.1		267.6
500	35.7	38.5	28.2	30.7	98.3	16.8	40.1	54
750	40.1	39.1	38.2	11.4	14.2	20.9	21.3	30.2
1000	42.0	30.3	9.6	8.5	37.2	8.9	14.1	31.5
1500		6.8		7.2		16.6		33
2000	3.4		18.5		3.4		16.6	
2500		4.3		3.0		12.6		19.8
3000	3.4		2.0		4.5		17.8	
4000		3.8		1.1		13.7		6.9
6000	2.3		1.1		0.9		6.8	
8000	1.1		0.9		1.7		1.7	
16000	0.8						1.1	

Table 5: Lube Range (C21-C32) Hydrocarbons for Hibernia EEM Sediment Stations for 1999. Values are in mg/kg.

Distance from Rig (m)	Radial							
	1	2	3	4	5	6	7	8
250		14.7		7.7		5		11.7
500	3.1	4	2.5	2.1	3.6	2.7	3.3	4.1
750	3.6	3.7	2.7	2.7	3.1	3.1	2	3
1000	3.2	3.1	2.8	2.7	2.4	3.3	3.6	4.8
1500		1.1		1.6		2.3		3.7
2000	1.4		7.3		1.5		3.4	
2500		1.3		0.9		6.7		4.8
3000	1.3		1.2		2.3		4.9	
4000		2.2		0.4		9.8		4
6000	1.3		1.2		1.3		8.8	
8000	1.1		1.6		2.3		2.7	
16000	1.7						2.2	

6. EXTRAPOLATIONS OF SIZE OF TOXIC ZONES

Excepting the 250 m stations near the Hibernia GBS, concentrations of lube range hydrocarbons appear to represent general background conditions. However diesel range hydrocarbons, which are found in synthetic base oils and consequently drill cuttings, displayed a "gradient". We can compare the levels of diesel range hydrocarbons found around the GBS to the threshold level of diesel range hydrocarbons found to be acutely toxic in sediment samples mixed with

Hibernia cuttings. We can further extrapolate to number of years to reach toxicity thresholds in sediments at varying distances from the rig assuming constant yearly inputs. This is presented in Table 6. It is noted that upwards of 500 years would be required to reach toxicity thresholds 1000 m from the rig sites.

Table 6: Mean Values of Diesel Range Hydrocarbons Extending from the GBS, Percentage of Threshold for Acute Toxicity and Years to Reach Acute Toxicity Threshold Assuming Constant inputs.

Distance from GBS (m)	mean level (mg/kg)	% of Toxicity Threshold	Years to Reach Toxicity Threshold
250	164.4	2.6	76
500	42.8	0.68	294
750	26.9	0.43	468
1000	22.8	0.36	553
1500	15.9	0.25	792
2000	10.5	0.17	1200
2500	9.9	0.16	1273
3000	6.9	0.11	1826
4000	6.4	0.10	1969
6000	2.8	0.044	4500
8000	1.4	0.022	9000
16000	1.0	0.016	12600

Approximately 36% of the wells have been drilled at the Hibernia site (personal communication Rick McCubbin, Hibernia Management and Development). Given the level of diesel range hydrocarbons presently found around the GBS, extrapolations can be carried out on the percentages of toxicity thresholds that will be found at varying distances from the rig over the life of the project. This extrapolation is presented in Table7. It is noted that approximately 1% of the toxicity threshold would be reached at 1000 m over the life of the project.

Table 7: Percentage of Threshold of Toxicity Reached Over the Life of the Project Assuming 36% of the Wells Have Been Drilled.

Distance from GBS (m)	Percentage of Threshold of Toxicity for Diesel Range Hydrocarbons
250	7.2
500	1.9
750	1.2
1000	1.0
1500	0.69
2000	0.47
2500	0.44
3000	0.31
4000	0.28
6000	0.12
8000	0.061
16000	0.044

CONCLUSIONS

Microtox® and amphipod bioassays are commonly used in sediment monitoring programs and are presently being used at some petroleum development sites on the east coast of Canada. Dose response relationships have been derived for these monitoring surrogates in studies with Hibernia source cuttings containing an aliphatic hydrocarbon based synthetic fluid. The cuttings demonstrated a very low acute toxicity potential with both species. Extrapolations have been carried out as to possible size of toxic zones for these monitoring species stemming from use of the drilling fluid in question. These extrapolations indicate little or no risk even as close as 1000 m or less from the rig site over the life of the project. Risks could also be further reduced at development sites in deeper waters or sites with stronger currents and thus greater potential for particle dilution and dispersion. The results of this study also indicate little potential for cumulative effects on sediment monitoring surrogates arising from other development sites using similar drilling muds.

ACKNOWLEDGEMENTS

We thank the Program on Energy Research and Development for providing support for these studies, Dave Taylor and Rick McCubbin, Hibernia Management and Development, for providing samples of cuttings and permitting use of Hibernia monitoring data and Urban Williams, Terra Nova, for information on the synthetic drilling fluid found in the cuttings.

REFERENCES

Armsworthy, S.L., P.J. Cranford, K. Lee, and K. Querbach. 2000. A new EEM approach for oil and gas based on hazard and risk assessments. I. Use of scallops to monitor the potential hazard of chronic discharges of synthetic drilling mud, p. 14-15. *In* K.C. Penney, K.A. Coady, M.H. Murdoch, W.R. Parker and A.J. Niimi [ed.]. Proceedings of the 27th Annual Aquatic Toxicity Workshop: October 1-4, 2000, St. John's, Newfoundland. Can. Tech. Rep. Fish. Aquat. Sci. 2331. 139 p.

AZUR Environmental. 1999. *MicrotoxOmni for Windows 95/98*, ver. 1.18, CD-ROM. AZUR Environmental, Carlsbad CA.

Cranford, P.J., S. Armsworthy, and K. Querbach. 2000. Chronic toxicity of synthetic oil-based drilling mud to sea scallops. Gordon, p. 33-34. *In* D.C. Gordon Jr., L.D. Griffiths, G.V. Hurley, A.L. Muecke, D.K. Muschenheim and P.G. Wells [ed.]. Understanding the environmental effects of offshore hydrocarbon development. Can. Tech. Rep. Fish. Aquat. Sci. 2311. 82 p.

Cranford, P.J., K. Lee, J.W. Loder, T.G. Milligan, D.K. Muschenheim and J. Payne. 2001. Scientific considerations and research results relevant to the review of the 1996 Offshore Waste Treatment Guidelines. Can. Tech. Rep. Fish. Aquat. Sci. 2364: vi + 25 p.

Frode Consulting. 1999. Dispersion and effects of synthetic drilling fluids on the environment: Biological survey, long-term effect of oil and produced water, chemicals and oil spill contingency. Technical Report, Ministry of Oil and Energy. Report No 99-3507, Revision no. 01, 49 p.

GESAMP (IMO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution) 1993: Impact of Oil and Related Chemicals and Wastes on the Marine Environment. *Rep. Stud. GESAMP* (50): 180 p.

JWEL Project No. 1355-1599. Hibernia Production Phase Environmental Effects Monitoring Program – Year Two of Production. May 2000.

Microbics Corporation. 1992. Microtox Update Manual, December 1992. Microbics Corporation, Carlsbad CA, 134 p.

Neff, J. 1987. Biological effects of drilling fluids, drill cuttings and produced waters. *In* Long-term Environmental Effects of Offshore Oil and Gas Development. *Edited by* D.F. Boesch and N.N. Rabalais. Elsevier Science Publishing Co., New York 469-538 p.

Payne, J.F., L.L. Fancey, J. Hellou, M.J. King and G.L. Fletcher. 1995. Aliphatic hydrocarbons in sediments: a chronic toxicity study with winter flounder (*Pleuronectes americanus*) exposed to oil well drill cuttings. Can. J. Fish. Aquat. Sci. 52: 2724-2735.

Payne, J., L. Fancey, C. Andrews, J. Meade, F. Power, K. Lee, G. Veinott and A. Cook. 2001. Laboratory exposures of invertebrate and vertebrate species to concentrations of IA- 35 (Petro-Canada) drill mud fluid, production water and Hibernia drill mud cuttings. Can. Data Rep. Fish. Aquat. Sci. No. 2560: iv + 27 p.

Porebski, L., K. Doe, B. Zajdlik, D. Lee, P. Pocklington, G. Atkinson and J. Osborne. 1998. Interpretative guidance for bioassays using pollution gradient studies. Belledune, New Brunswick, Environmental Protection Series, Environment Canada, March 1998, 155 p.

Ray, J.P. 1989. Offshore drilling wastes issues, p. 848-860. *In* Drilling Wastes. F.R. Englehardt, J.P. Ray and A.H. Gillam [ed.]. Elsevier Science Publishing Co., New York.

Tay, K.L., Doe, K.G., MacDonald, A.J. and Lee, K. 1997. Monitoring of the Black Point Ocean Disposal Site, Saint John Harbour, New Brunswick, 1992-1994, Environment Canada, Atlantic Region, Internal Report, ISBN: 0-662-25655-5, Cat.no. En40-214/9E, 133 p.

Wang, H., J.F. Payne, and A.D. Rahimtula. 2000. Effect of drilling fluid on enzymes involved in metabolism of chemicals, p. 32. *In* D.C. D.C. Gordon Jr., L.D. Griffiths, G.V. Hurley, A.L. Muecke, D.K. Muschenheim and P.G. Wells [ed.]. Understanding the environmental effects of offshore hydrocarbon development. Can. Tech. Rep. Fish. Aquat. Sci. 2311: 82 p.